



IEEE Standard for Inertial Systems Terminology

STANDARDS

IEEE Aerospace and Electronic Systems Society

Developed by the
Gyro and Accelerometer Panel

IEEE Std 1559™-2022
(Revision of IEEE Std 1559-2009)



IEEE Standard for Inertial Systems Terminology

Developed by the

Gyro and Accelerometer Panel
of the
IEEE Aerospace and Electronic Systems Society

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IEEE SA Standards Board

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Abstract: Terms and definitions relating to aided and unaided inertial systems for navigation, guidance, orientation, stabilization, and related applications are presented. Usage as understood by the inertial systems community is given preference over general technical usage of the terms herein. The criterion for inclusion of a term and its definition in this document is the term's usefulness as related to inertial systems technology.

Keywords: IEEE 1559™, inertial systems technology, inertial systems terminology

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Introduction

This introduction is not part of IEEE Std 1559-2022, IEEE Standard for Inertial Systems Terminology.

This standard is a listing of terms and definitions used in the development, manufacture, test, and use of aided and unaided inertial systems for navigation, guidance, orientation, stabilization, and related applications. Usage as understood by the inertial systems community is given preference over general technical usage of the terms herein. The criterion for inclusion of terms and definitions in this standard is their general usefulness as related to aided and unaided inertial systems technology. This standard is a companion to IEEE Std 528™, IEEE Standard for Inertial Sensor Terminology.^{6,7}

Radio navigation terms are listed insofar as they pertain to aiding inertial navigation systems. However, an exhaustive list of radio navigation terminology is not given.

In this standard, the symbol g is used to denote a unit of acceleration equal in magnitude to the local value of gravity at a test site or the standard value $9.806\,65\text{ m/s}^2$. The symbol g is thus distinguished from g which is the standard symbol for gram.

Abbreviations and acronyms are listed alphabetically in the body of the text, with a reference to the spelled-out term in the text for the full definition. For the purposes of this standard, an acronym (such as AHRS and ISA) is pronounced as a word, whereas, each letter of an abbreviation (such as GPS and INS) is pronounced. Abbreviations and acronyms are frequently used in definitions of other terms.

This standard represents a consensus of manufacturers and users in industry, government agencies, and other interested groups. When necessary, the needs of the inertial systems community have been given preference over general technical usage. In general, definitions that might be found in a standard textbook have not been included, such as “orthogonality.” All definitions contained herein are based on a right-handed coordinate system.

This standard uses spaces as a delimiter to divide numbers into groups of three, instead of commas or periods. In the case where a number is only four digits long, the space is not used. Examples include:

- 73 722
- 7372
- 0.133 47
- 73 722.133 47

This standard highlights self-referenced terms in **bold** type.

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1. Overview

1.1 Scope

This standard provides a source of definitions of terminology used in the development, manufacture, and test of aided and unaided inertial systems used for navigation, guidance, orientation, stabilization, and related applications. This is a companion document to IEEE Std 528™. ^{8,9} ~~1,2~~

1.2 Purpose

There is no consistent definition of terms that have arisen in the evolution of aided and unaided inertial navigation and related systems. This standard is intended to serve as a basic reference for producers and users of such systems, for preparing industry standards, and for the interpretation of published technical reports.

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1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{10, 11}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

1.3 Related standard

~~Only inertial system related terms are given in this standard. Inertial sensor terms are covered in IEEE Std 528, IEEE Standard for Inertial Sensor Terminology.~~

2. Normative references

3. Definitions, acronyms, and abbreviations

3.1 Definitions

acceleration: The time rate of change of an object's **velocity**. Acceleration is the sum of **gravitational acceleration** and **nongravitational acceleration**.

¹⁰ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

¹¹ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

NOTE—In order to denote **angular acceleration**, the qualifying word “angular” ~~is must be~~ used.³

aiding: The use of noninertial information to control the unbounded growth of inertial **navigation** errors.

NOTE—Aiding types include **altimeters**, **depth meters**, **odometers**, **air speed indicators**, **radars**, **sonars**, **speed logs**, **terrain recognition**, **map matching**, **magnetometers**, **magnetic compasses**, **space- or terrestrial-based radio navigation systems**, **stellar aiding**.

aircraft-based augmentation system (ABAS): An augmentation system that integrates additional aircraft sensor information into the calculation process.

air speed: The speed, especially of an aircraft, relative to the air.

air speed indicator: A device that measures the **air speed** of a vehicle.

NOTE—An air speed indicator can be used for inertial system **aiding**.

alignment: The process of determining or controlling the orientation of the **ISA** relative to a reference frame. See: **at-sea alignment**; **gyrocompass alignment**; **in-flight alignment**; **in-motion alignment**; **moving base alignment**; **stored heading alignment**; **transfer alignment**.

Allan Deviation: The square root of the **Allan Variance**.

Allan Variance: A characterization of the noise and other processes in a time-series of data as a function of averaging time. It is one half the mean value of the square of the difference of adjacent time averages from a time series as a function of averaging time.

almanac: Information transmitted by each **GNSS** satellite⁷, which describes the orbits and state (health) of every satellite in the **GNSS** constellation.

NOTE 1—Almanac data facilitates the rapid acquisition of satellites after the **GNSS** receiver is powered ~~turned~~ on.

³ ~~Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.~~

NOTE [2](#)—Almanac orbital data is less accurate than **ephemeris** data, but remains valid for a longer period of time.

altimeter: An instrument that measures the **altitude**. There are two common types, ~~as follows:~~

- a) Barometric altimeters, which typically measure relative to sea level
- b) Ranging altimeters, which measure relative to the local terrain.

NOTE—An altimeter can be used for **inertial system** aiding.

altitude: The height of an object with respect to a reference level or point.

NOTE—Common reference levels include the **geoid** and the **ellipsoid**.

analytic platform frame: A rectangular coordinate system into which the **ISA frame** outputs are transformed.

NOTE—The analytic **platform frame** is the mathematical equivalent of the **stabilized platform frame** in a gimbaled **IMU**.

angular acceleration: The time rate of change of an object's **angular velocity**.

[angular rates:](#) See: [angular velocity](#).

[angular velocity:](#) The time rate of change of an object's orientation relative to a reference frame.

anti-spoofing (A-S): Use of encryption to prevent false **GNSS** transmissions from corrupting the true **GNSS** transmissions.

atomic clock: A **clock** that is [locked](#) ~~slaved~~ to the frequency provided by an atomic transition.

NOTE [1](#) ~~2~~—Atomic clocks are used to generate reference time systems, such as **UTC** and **navigation satellite time**.

NOTE [2](#) ~~4~~—The cesium atomic clock provides [a time](#) ~~the fundamental definition of the SI second,~~
~~with a present~~ accuracy [on the order](#) of [one](#) ~~a~~ part in 10^{14} .

at-sea alignment: (A) Transfer alignment of an INS in an aircraft that is sitting on a ship's deck using the

attitude, position and/or velocity from the ship's INS. (B) alignment of a ship's INS at sea using aiding.

attitude: The orientation of a vehicle with respect to a reference frame.

NOTE—In local level mechanizations attitude is usually expressed by roll, pitch, and yaw angles.

attitude and heading reference system (AHRS): An inertial system that estimates the attitude and heading of a vehicle. The attitude is with respect to the local level coordinate frame system.

attitude integration: The process of integrating gyroscope data in three dimensions to provide orientation of an ISA relative to a reference coordinate frame. Attitude integration should must account for non-commutativity of rotations and commonly uses quaternions or direction cosine matrices. See: direction cosine matrix integration algorithm; quaternion integration algorithm.

NOTE—Some commonly used forms of attitude, such as Euler angles, exhibit singularities and are not well suited for integration.

attitude matching: The process of determining the attitude and heading of an a-slave inertial system using the attitude and heading of a reference master system. See: transfer alignment.

NOTE—Compensating for known orientation differences speeds will-speed up the process.—See: transfer alignment.

attitude rate matching: See: gimbal matching.

attitude rates: See: Euler rates.

augmentation system: System to improve the performance (accuracy, integrity, continuity, coverage) of a radio navigation system by adding extra signal sources, such as pseudolites; or to improve the accuracy by broadcasting differential correction information. See: differential radio navigation.

authorized user: An operator of GNSS user equipment that has been provided the means to access restricted-use signals.

autopilot: Automatic control of the **attitude** and **course** of a vehicle. *See:* **flight control**; **guidance**; **steering**.

azimuth: The angle from a horizontal reference direction to the horizontal projection of the direction of interest; positive is north to east.

BDS simulator: A type of radio navigation simulator.

BeiDou navigation satellite system (BDS): A Chinese space-based radio navigation system with control, space, and user segments.

NOTE 1—The baseline space segment consists of 3 GEO satellites, 3 IGSO satellites, 24 MEO satellites, and spares. The GEO satellites are at an altitude of 35 786 km and are located at longitudes 80°, 110.5° and 140°. The IGSO satellites are also at an altitude of 35 786 km. The MEO satellites are at an altitude of 21 528 km. The orbital inclination of the IGSO and MEO satellites is 55°.

NOTE 2—The 3 GEO and 3 IGSO satellites provide a regional overlay constellation.

NOTE 3—BDS provides a radio navigation satellite service (RNSS), a satellite-based augmentation service (SBAS), a precision point positioning (PPP) service, a short message communication service (SMCS), and a search and rescue (SAR) service. RNSS is the global open navigation signal. SBAS is the global navigation correction service. PPP is the local navigation correction service. SMCS provides both regional and global messaging. The SAR service allows global maritime, aviation and land search and rescue.

NOTE 4—BDS can be used for inertial system aiding.

BeiDou time (BDT): BDT is a navigation satellite time expressed as a week number (modulo 8192, 0 to 8191) and a time of week in seconds. BDT started at 00:00 UTC on Sunday January 1, 2006. At that time, BDT week and seconds were both equal to zero.

blended solution: A solution formed by combining the weighted outputs of different sensors and/or systems. The resulting solution is generally more accurate than that provided by any of the individual sensors and/or systems. [See: data fusion.](#)

[NOTE—](#)A **Kalman filter** is usually used to perform the blending [See: data fusion.](#)

body acceleration: A vector whose components are the thermally-compensated accelerometer outputs expressed in a vehicle's **body ~~reference~~-frame**. [See: lateral acceleration; longitudinal acceleration; normal acceleration.](#)

NOTE—The magnitude of body acceleration indicates the measured value of local gravity when the vehicle is at rest.

body angular rates: Angular velocities of a vehicle, expressed in a **body ~~reference~~-frame**.

body ~~reference~~ frame: A rectangular coordinate system with origin and orientation fixed relative to the vehicle body.

body velocity: The vehicle's **velocity** vector relative to a reference frame as expressed along the axes of its **body ~~reference~~-frame**.

boresighting: The process of aligning the axes of a system with the reference axes of a vehicle. Boresighting can be accomplished using mechanical adjustment or a sequence of mathematical rotations to resolve the system outputs into the reference coordinate system.

[C/A code:](#) The unencrypted Coarse Acquisition GPS ranging code that is the basis for civilian GPS use.

calibration: Estimation of the gyroscope and accelerometer biases, scale factors, input axis misalignments, temperature sensitivities, and other parameters in an **inertial system** when subjected to known inputs.

NOTE 1—Calibration can be accomplished by orienting the **ISA** at known angles to the **local vertical** and by imparting angular velocities about various axes.

NOTE 2—Some inertial sensor parameters require factory calibration valid for the service life of the sensor.

NOTE 3—Further refinement of the calibrated parameters in an aided inertial system can be accomplished by comparing the inertial data with the **aiding** data, especially if vehicle maneuvers excite error effects.

calibration error: The uncertainty in the value of a calibrated parameter due to measurement errors and modeling limitations.

carouseling: Continuous rotation of an **ISA** about one or more axes to reduce **navigation** errors due to gyroscope and accelerometer bias errors.

NOTE 1—Periodic reversal of the sense of rotation reduces scale factor **wind-up** errors introduced by the carousel process.

NOTE 2—**Strapdown** algorithms are used to process the gyro and accelerometer outputs.

carrier phase: A measure of the range between a satellite and a user expressed in units of cycles of the carrier frequency.

NOTE—There is an ambiguity in the number of whole carrier cycles between the satellite and the user that cannot be directly measured.

celestial navigation: Navigation using observations of celestial bodies with known **ephemerides**.

Chaika: A hyperbolic navigation system.

circular error probable (CEP): The radius of the origin-centered circle, which contains 50% of two-dimensional error samples, for example horizontal **position** errors.

NOTE 1—In some cases, a CEP based on unbiased errors can be specified but, in such instances, a mean error should ~~must~~ also be specified.

NOTE 2—In some cases, a circle containing a different percentage of samples may be specified, for example 95%.

clock: A device that uses an **oscillator** to generate a **time** reference. *See:* **atomic clock**.

NOTE—Clocks can have **acceleration**, temperature, and other environmental sensitivities.

clock synchronization: The locking of multiple clocks to a common reference to ensure a common time base.

NOTE—An alternative to synchronization is the use of **data time tags**.

coning: Motion of an axis that results from a combination of oscillatory motions about perpendicular axes and generally describes a cone. An apparent angular drift rate is generated about the coning axis equal to the solid angle swept per unit time and is a function of the amplitudes and frequencies of oscillations present and the phase angles between them.

NOTE—In a **strapdown** inertial system high rate (typically on the order of hundreds or thousands of hertz) sampling and/or compensation algorithms are required for proper compensation of the apparent drift rate.

coning algorithm: An algorithm that compensates for **coning** motion in a **strapdown** inertial system. It combines samples from the three gyroscopes to form a coning correction that compensates for the apparent drift rate and for finite sampling of the gyroscope outputs.

[NOTE 1](#)—Mathematically, the purpose of the coning algorithm is to provide a high-fidelity approximation of the rotation vector representing the composite rotational motion across one attitude integration or update period.

[NOTE 2](#)—High performance coning algorithms utilize several samples of gyro data per attitude integration period.

control moment gyro: Gimbaled spinning wheel gyroscope for controlling vehicle **attitude** through the reaction caused by ~~torqueing~~ [torquing](#) the **gimbals**.

control segment (space-based radio navigation system): The ground sites of a **space-based radio navigation system** that obtain telemetry and tracking data, and control the satellites. They determine the orbits and monitor the health of the satellites. They send the satellite **ephemeris** and status data, and station keeping, **clock** correction, and other commands to the satellites.

coordinated universal time (UTC): The ~~Greenwich~~-atomic clock based time determined broadcast by the [Bureau International des Poids et Mesures](#), with leap seconds determined by the [International Earth Rotation and Reference Systems Service](#) ~~national time services~~.

[NOTE 1](#)—A leap second is introduced in the time service broadcasts if required on either January 1 or July 1 to keep UTC within 0.9 s of ~~Greenwich mean solar time (UT1)~~.

[NOTE 2](#)—UTC is a “paper” time and thus not available for broadcast. However, approximations with differing levels of accuracy are available for broadcast from various worldwide locations.

[NOTE 3](#)—The UTC second is the international system (SI) second.

[course:](#) The time series of positions that were followed (or are planned to be followed) to get from one position to another.

craft rate: The **angular velocity** resulting from level flight over the curvature of the earth. Craft rate is $V_h/(R_e + h)$, where V_h is the **velocity** in the horizontal plane, R_e is the local radius of curvature of the earth in the direction of V_h , and h is the **altitude**.

data fusion: The process of combining diverse types of data [to gain the benefits of each data source while mitigating their shortcomings](#).

[NOTE 1](#)—**Inertial systems** often use data fusion to combine inertial sensor outputs with the outputs of various **aiding** devices producing an output that is commonly referred to as a **blended solution**. These systems are often referred to as aided or integrated inertial systems.

[NOTE 2](#)—Data fusion techniques include **Kalman filter** and **maximum likelihood estimation**.

data latency: The time interval between the occurrence of an event and the availability of its measurement.

data time tag: The time associated with the measurement of an event that best represents when the event occurred.

datum: A mathematical model of the earth, which includes a reference **ellipsoid** with a specified point of origin.

[NOTE 1](#)—A datum can be optimized globally, such as **WGS-84**, but is usually optimized for a local area.

[NOTE 2](#)—A datum may include other geodetic data, such as a **gravity model** and the earth rotation rate.

dead reckoning: **Navigation** using information provided by the initial **position** and the measured time history of direction and speed.

NOTE—Navigation errors may be introduced by wind or ocean currents, magnetic anomalies, etc.

[delta range:](#) The change in the range between a satellite and a user over a measurement period.

Decca: A ~~discontinued~~ hyperbolic navigation system.

depth meter: Measures the distance from a submerged vessel to the surface. This is typically accomplished by measuring the water pressure.

NOTE—A depth meter can be used for **inertial system** aiding.

[differential BDS:](#) A type of differential radio navigation system.

[differential Galileo:](#) A type of differential radio navigation system.

differential GLONASS: A type of **differential radio navigation** system.

[differential GNSS:](#) A type of differential radio navigation system.

differential GPS: A type of **differential radio navigation** system.